Deterministic Modeling of Water Entry and Drop of An Arbitrary Three-Dimensional Body — A Building Block for Stochastic Model Development

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LONG-TERM GOAL

The ultimate goal is to develop a robust and accurate physics-based hydrodynamics model for predicting water entry and subsequent drop of a mine-shaped three-dimensional body. The key capability of the model is to provide an input of the velocity and motion of a near-bottom mine for mine burial predictions. Such a deterministic model is an essential building block in the development of stochastic models for mine burial predictions.

OBJECTIVES

The specific objectives are:

- To develop theoretical and computational predictions of the motion of a three-dimensional body impacting the water surface at arbitrary entry velocity and angle

- To develop an effective dynamical model for the simulation of the six degree-of-freedom motions of a three-dimensional body inside water including the viscous effect associated with vortex shedding and flow separation and the forcing due to surface waves and current

- To conduct scaled laboratory tests at the water tunnel of MIT to establish a data base of the drag coefficients of different mines at various velocities and orientations

- To provide deterministic data sets of the transfer functions of the velocity and motion of mine-shaped bodies during their entry into water and dropping toward the bottom for probabilistic mine burial prediction modeling

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14. ABSTRACT
The ultimate goal is to develop a robust and accurate physics-based hydrodynamics model for predicting water entry and subsequent drop of a mine-shaped three-dimensional body. The key capability of the model is to provide an input of the velocity and motion of a near-bottom mine for mine burial predictions. Such a deterministic model is an essential building block in the development of stochastic models for mine burial predictions.

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APPROACH

For water impact, to account for the large range of physical/geometrical parameters, we develop and apply a multi-level approach utilizing theoretical, semi-analytic, and direct computational tools in the respective regimes in which they are valid and most efficient. Specifically, we develop: (i) an analytic model based on the theory of von Karman for water impact of arbitrary three-dimensional bodies; (ii) an effective semi-analytic model using the generalized Wagner's approach (Mei, Liu & Yue 1999) for water entry of mine-shaped bodies at arbitrary entry velocity and angle; and (iii) a nonlinear numerical simulation model based on the Mixed-Euler-Lagrangian approach (Liu, Xue & Yue 2001) for general water impact of three-dimensional bodies including the effects of free-surface jet and cavity.

For the drop of a three-dimensional bluff body in the water, we develop a dynamical model for the prediction of six degree-of-freedom motions of the body. The effect of vortex shedding, flow separation and cavitation is accounted for based on the use of empirical quasi-static drag coefficient. The environmental forcing due to surface waves, bottom and currents is evaluated using an efficient spectral algorithm (Liu, Dommermuth & Yue 1992). To determine the drag coefficients associated with vortex shedding and flow separation, we conduct scaled laboratory tests in the water tunnel of MIT.

For calibration and validation of the water entry and drop models, the model predictions are compared with the tank and field drop tests which are to be conducted by the other research team also funded by the ONR mine burial research program.

WORK COMPLETED

The major work completed includes:

- Development of a simple analytic model for the prediction of the horizontal and vertical motions of cylindrical mines released inside water, and calibration and validation of the model against available field-test data.

- Development of water entry models for three-dimensional mine-shaped bodies impacting water surface at arbitrary velocity and entry angle using both the von Karman method and the generalized Wagner’s approach. The models are validated by comparisons to available existing theoretical solutions and tank/field test data.

- Development and validation of an effective dynamical model for the prediction of the six degree-of-freedom motions of a three-dimensional body dropping through water; development of an effective algorithm to account for viscous effects on the motions of mine-shaped bodies; and investigation of the characteristics of the mine motions inside the water.

- Investigation on the modeling of the dynamics of caviation (trapped behind mines during water entry) and its effect on the motions of mines in the water.

- Providing assistance and guidance to the mine drop tests at the explosive test pond of NSWC-Carderock by the mine burial prediction program led by Dr. Philip Valent of NRL, Stennis

Space Center; and preparation of scaled model tests of the drag coefficients of mines in the water tunnel of MIT.

RESULTS

The present models are validated against the preliminary field drop tests conducted by the mine burial prediction group led by Dr. Philip Valent of NRL at East Bay and NGLI Site 9 in November 2000. Comparisons with the Carderock tank drop tests are currently under investigation. Unlike the existing tools (such as IMPACT28), our models are capable of predicting all distinguished features of the mine motions observed in the field tests and obtaining satisfactory quantitative comparisons with the field measurements. Figure 1 shows a sample comparison between the present model prediction and the field-test data for the vertical acceleration of a horizontal cylindrical mine during its drop through the water to the bottom. The mine has a length $\boldsymbol{L}$=1.5m, a diameter $\boldsymbol{D}$=0.47m and a density ρ=2093 kg/m^3. The mine is released from rest slightly below the water surface. The agreement between the model prediction and the measurement is quite acceptable. Figure 2 shows the similar comparison for the same mine but dropping from 1.0m above the water surface during the phase of water impact. Good agreement between the model prediction and the field measurement is again obtained. This validates the present model for water impact of mines.

We also apply the present models to investigate the characteristics of the mine motions with different physical and geometrical parameters of mines such as aspect ratio, initial impact velocity and center of mass. Figure 3 shows a sample result of the trajectories of a (synthetic) horizontal cylindrical mines with three different distances ($\boldsymbol{C}_g$= 0.1m, 0.2m and 0.3m) between the center of mass and the center of geometry. It is shown that the mine motion is critically affected by $\boldsymbol{C}_g$.

IMPACT/APPLICATION

Proper modeling of the hydrodynamics of mines impacting the water surface and dropping through the water to the bottom is essential for reliable mine burial predictions. Our work provides the necessary deterministic transfer functions for water entry and drop which are essential input to the stochastic mine burial prediction model. Such accurate predictions of the hydrodynamics of mines cannot be obtained using the existing tools such as IMPACT25 (or IMPACT28).

TRANSITIONS

The hydrodynamic model developed in this study will be incorporated into a stochastic model for the prediction of mine burial. Such a stochastic model can provide useful information on mine burial for mine deployment or sweeping.

REFERENCES

Liu, Y., Dommermuth, D.G. & Yue, D.K.P. 1992 A high-order spectral method for nonlinear wave-body interactions. *J. Fluid Mech.* **245,** 115-136.

Liu, Y., Xue, M. & Yue, D.K.P. 2001 Computations of fully-nonlinear three-dimensional wave-wave and wave-body interactions. Part2. Nonlinear waves and forces on a body. *J. Fluid Mech*. **438**, 41-66.

Mei, X., Liu, Y. & Yue, D.K.P. 1999 On the impact of two-dimensional bodies. *Applied Ocean Research* **21**, 1-15.

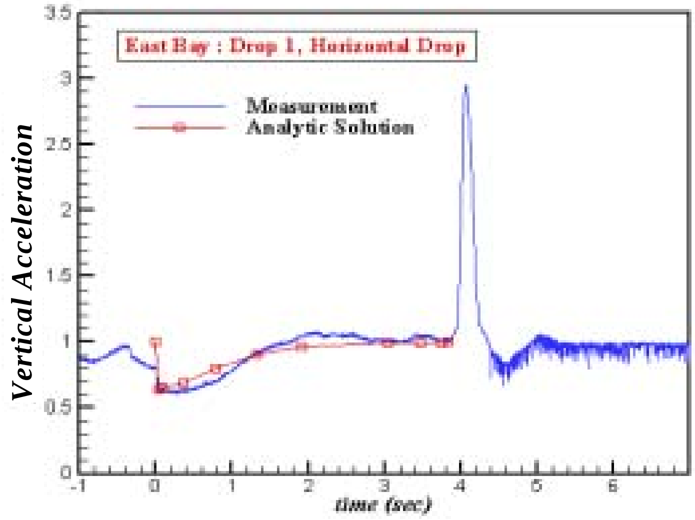

Figure 1. The time history of the vertical acceleration (normalized by the gravitational acceleration) of a horizontal cylindrical mine dropping slightly below the water surface. The comparison is made between the simulation using the present model and the field test data.

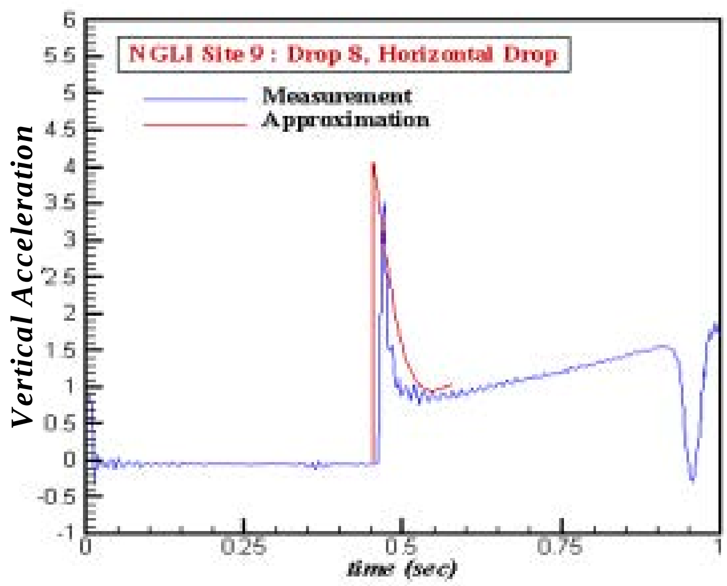

Figure2. The time history of the vertical acceleration (normalized by the gravity acceleration) of a horizontal cylindrical mine dropping from 1.0m above the water surface (during water impact). The comparison is made between the simulation using the present model and the field test data.

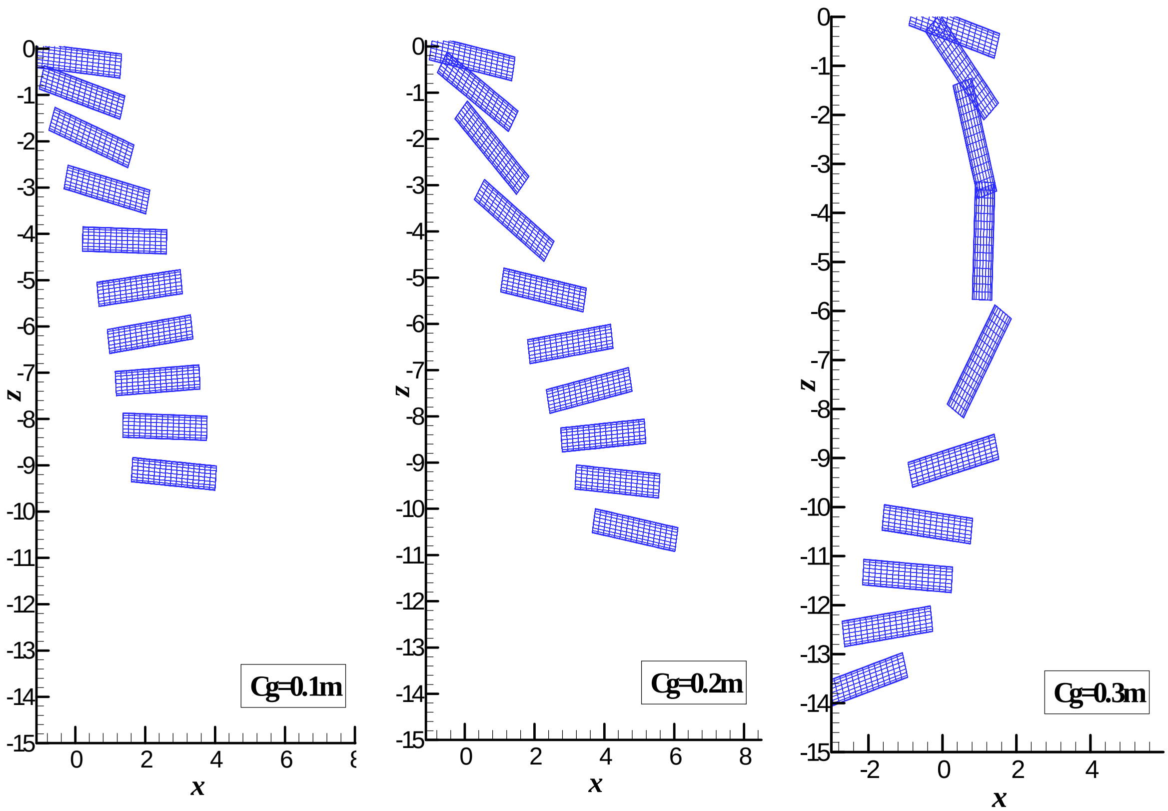

Figure 3. Simulation results (by the present model) of the trajectories of a horizontal mine with three different locations of the center of mass. The mine is released slightly below the water surface.